Dockx K, Alcock L, Bekkers E, Ginis P, Reelick M, Pelosin E, Lagravinese G, Hausdorff JM, Mirelman A, Rochester L, Nieuwboer A.

Fall-prone older people's attitudes towards the use of virtual reality technology for fall prevention.

Gerontology (2017)

DOI: https://doi.org/10.1159/000479085

Title: Fall-prone older people's attitudes towards the use of virtual reality technology for fall-prevention

Short title: Attitudes towards virtual reality

Authors: Dockx K.[1], Alcock L.[2], Bekkers E.[1], Ginis P.[1], Reelick M.[3], Pelosin E.[4], Lagravinese G.[5], Hausdorff JM.[6], Mirelman A.[6], Rochester L.[2], Nieuwboer A[1].

[1] Department of Rehabilitation Sciences, KU Leuven, Leuven, Belgium

[2]Institute of Neuroscience, Newcastle University, New castle, UK

[3]Department of Neurology, Geriatric Medicine, and Radboud Alzheimer Center, Radboud university medical center, Nijmegen, the Netherlands

[4] Department of Neurosciences, University of Genoa, Genoa, Italy

[5] Department of Neurology, Tel Aviv University, Tel Aviv, Israel

[6] Department of Physical Therapy, Tel Aviv University, Tel Aviv, Israel

Corresponding author:

Dockx Kim, PhD

Address: KU Leuven, Faculty of Kinesiology and Rehabilitation Scincces, Department of Rehabilitation Sciences, Tervuursevest 101, 3001 Leuven, Belgium

Phone number: 0032 472 21 37 33

E-mail: kimdockx@gmail.com

Abstract

Background

Virtual reality (VR) technology is a relatively new rehabilitation tool that can deliver a combination of cognitive and motor training for fall prevention. The attitudes of older people to such training are currently unclear.

Objective

This study aimed to investigate: 1) the attitudes of fall-prone older people towards fall prevention exercise with and without VR; 2) attitudinal changes post intervention with and without VR; and 3) user satisfaction following fall prevention exercise with and without VR.

Methods

281 fall-prone older people were randomly assigned to an experimental group receiving treadmill training augmented by VR (TT+VR, n=144) or a control group receiving treadmill training alone (TT, n=137). Two questionnaires were used to measure 1) attitudes towards fall prevention exercise with and without VR (AQ); and 2) user satisfaction (USQ). AQ was evaluated at baseline and post-intervention. USQ was measured post-intervention only.

Results

The AQ revealed that most participants had positive attitudes towards fall prevention exercise at baseline (82.2%) and post-intervention (80.6%; p=.144). In contrast, only 53.6% was enthusiastic about fall-prevention exercise with VR at baseline. These attitudes positively changed post-intervention (83.1%; p<.001), and 99.2% indicated that they enjoyed TT+VR. Correlation analyses showed that post-intervention attitudes were strongly related to user satisfaction (USQ: r=.503; p<.001).

Conclusions

Older people's attitudes towards fall prevention exercise with VR were positively influenced by their experience. From the perspective of the user, VR is an attractive training mode and thus improving service provision for older people is important.

Introduction

Falls constitute a significant health risk. With ageing, 30% of the healthy older population becomes susceptible to falling[1], whereas in adults with Parkinson's disease (PD)[2] or mild cognitive impairment (MCI)[3] more than 60% fall each year. According to a systematic review by Gillespie et al., exercise interventions are successful, at least to some degree, in reducing fall rates and risk[4]. Advancements in technology have enabled fall prevention exercise to be augmented by virtual reality (VR)[5]. Both randomized and non-randomized controlled trials have reported positive effects of VR exercise on gait, balance, and cognition[6-9]. This was interpreted as a result of the unique property of VR to concurrently stimulate both motor and cognitive functions, and to provide the participant with augmented feedback about performance. However, very little is known about older people's attitudes towards and user satisfaction about this relatively new rehabilitation tool.

Recently, we demonstrated the effectiveness of treadmill training with VR (TT+VR) and without (TT) on reducing fall rates in older adults[10]. In a sub-analysis of this large randomized trial, we aimed to investigate the attitudes of healthy fall-prone older people, those with mild cognitive impairment (MCI), and Parkinson's disease (PD) towards these two training modes and whether experience would change initial attitudes. We hypothesized that older adults would have a positive attitude towards regular fall-prevention exercise, but a reserved attitude towards VR exercise at baseline because of being unfamiliar with this technology-based intervention. After participants used the system and became more accustomed, we expected to see a positive attitude change and higher user satisfaction scores for those allocated to TT+VR as opposed to those in the TT group.

Methods

Study design

This study was part of an RCT entitled "Virtual reality Treadmill combined Intervention to improve Mobility and reduce falls in the Elderly" (FP7 project V-TIME-278169). The study was conducted at five clinical sites: 1) Lab for Gait & Neurodynamics, Tel Aviv Sourasky Medical Centre, Israel; 2) Department of Rehabilitation Sciences, KU Leuven, Belgium; 3) Institute of Neuroscience, Newcastle University, UK; 4) Department of Neurosciences, University of Genoa, Italy; and 5) Departments of Geriatric Medicine & Neurology, Radboud University Medical Centre, The Netherlands. Eligible participants were randomly assigned to an intervention group (TT+VR), or a control group (TT). A detailed description of the intervention and its findings are provided in the V-TIME protocol paper[11] and the RCT publication[10].

The current sub-analysis involved 281 participants, of the 302 originally randomized in the V-TIME study (Figure 1). These participants were assessed at baseline and immediately after the intervention.

Participants

Participants were stratified into three faller cohorts: healthy elderly fallers (HE-F, n=108), fallers with MCI (MCI-F, n=44) and fallers with PD (PD-F, n=129). Recruitment took place between January 2012 and January 2015.

Inclusion criteria: aged between 60 and 90 years; self-report of two or more falls in the previous six months; able to walk at least five minutes unassisted; adequate hearing and vision; stable medication in the past month which was anticipated to continue over the following six months. Exclusion criteria: psychiatric co-morbidity; clinical diagnosis of dementia or other severe cognitive impairment (Mini-Mental State Examination (MMSE) score <24)[12]; history of stroke, traumatic brain injury or other neurological disorders (other than PD or MCI); acute lower back or lower extremity pain; peripheral neuropathy; rheumatic and orthopedic diseases; and an inability to comply with the training.

MCI-F were included if they scored 0.5 on the Clinical Dementia Rating Scale (CDR)[13]. PD-F were included if they had a clinical diagnosis of idiopathic PD as defined by the UK Brain Bank criteria[14], Hoehn & Yahr stage (H&Y) II–III[15], and were currently being prescribed anti-parkinsonian medication.

A minimum of 15 sessions was required to complete the intervention, and <15 was classified as a drop-out and consequently excluded from the post-intervention analyses. All participants signed an informed consent form in accordance to the Declaration of Helsinki[16]. The study was approved by Ethics Committees in each of the participating clinical sites.

Interventions

Participants exercised three times per week for six weeks, including approximately 45 minutes per session. Both intervention cohorts walked on a treadmill, where gait speed and walking duration were progressively increased. The intervention was provided by trained therapists and care was taken to standardize training intensity across centers.

Intervention group: TT+VR

A custom-made VR system was developed to challenge and address known predictors of falling (e.g. obstacle negotiation, dual tasking, executive function), whilst creating a safe and motivating environment. The system consisted of a camera based motion capture system (Microsoft Xbox One Kinect and Microsoft LifeCam Studio) placed in front of the treadmill to enable movement registration of the participants' feet while walking. Brightly colored markers placed at the instep of the feet were used for optimized tracking. Recorded movements were then converted and relayed into the virtual environment in real-time and displayed on a large TV-screen (Figure 2).

The main goal of TT+VR was to train 'real life' gait. Obstacles of different sizes appeared at various frequencies and visibilities during treadmill walking, eliciting steps in both anterior (i.e. increasing step length) and vertical (i.e. elevating step height) directions. Immediate visual and auditory feedback as well as an overall success rate were provided.

Dual tasking abilities were continuously challenged, not only by means of the obstacle negotiation task, but also by providing the participants with a navigation task. For this task, 2 buttons were attached to the treadmill. When participants entered a cross-road in the VR, they had to press the left or right button to make a turn, respectively. Moreover, TT+VR was designed to offer distractors to stimulate cognitive processes needed for safe ambulation such as attention, executive function, response selection and motor planning.

All participants were continuously challenged by gradually increasing the difficulty levels as the training progressed. The motor task was challenged by increasing the speed and duration of the walk, starting with three 5 minute walks at 80% of normal walking speed in training session 1, to three 15 minute walks at 120% of normal walking speed in session 18. In addition, the cognitive tasks became more difficult by gradually increasing the number of obstacles, the height/length of the obstacles, the number of distractors, and the difficulty of the navigation task.

Control group: TT

Conventional treadmill training (TT) was provided without the VR component. Progression of gait speed and walking duration followed the same guidelines as in TT+VR. Detailed information regarding the interventions is provided in the protocol paper.

Outcome measures

Primary outcome measures

Two multiple choice questionnaires were developed and piloted extensively as part of the V-TIME study. The attitudes questionnaire (AQ) evaluated older people's attitudes towards fall prevention exercise with and without VR. The user satisfaction questionnaire (USQ) was designed to examine user satisfaction following intervention. Both AQ and USQ are paper and pencil questionnaires using binary scoring systems and a five-point Likert scale. Both questionnaires are available in Appendices 1-4.

The development of both questionnaires was based on extensive pilot testing performed at KU Leuven (Belgium). Here, a series of individual and focus group interviews were performed involving frequent fallers (PD-F: n=4; HE-F: n=6), caregivers (n=5), and experts (n=8) including geriatricians, physiotherapists, and researchers. Before the interviews, a PowerPoint presentation was given explaining the importance of fall prevention interventions and the possible added value of VR. Following this presentation, the attitudes, concerns, and thoughts of the interviewees towards fall prevention, treadmill training, and VR were explored. In the second phase, prototype questionnaires were developed and optimized based on individual interview sessions with frequent fallers (n=18) and professionals (n=27) at the Tel Aviv Sourasky Medical Centre (Israel) and KU Leuven (Belgium). The interviewees provided feedback on the relevance of the questions and whether or not they were clear. To meet the linguistic needs of all clinical centers, the questionnaires were translated by one of the participating researchers from English to Hebrew, Dutch, and Italian.

Attitudes questionnaire

The AQ was assessed prior to and following intervention. The baseline AQ contained three sections probing the following:

(i) Background experiences with exercise interventions, VR and computer games
(ii) Attitudes towards fall prevention exercise without VR
(iii) Attitudes towards fall prevention exercise with VR

Post-intervention, both cohorts received a different version of the questionnaire. Participants allocated to the TT group only received questions about part ii, attitudes towards fall prevention exercise without VR. In contrast, those allocated to TT+VR only received questions about part iii, attitudes towards fall prevention exercise with VR.

User satisfaction questionnaire

The USQ was assessed post-intervention. This 15-item questionnaire consisted of two sections investigating the:

i) Benefits and pitfalls of the intervention provided;
ii) Self-perceived improvements in physical and cognitive outcomes.

The USQ was based on other user-satisfaction instruments such as the Tele-healthcare Satisfaction Questionnaire-Wearable Technology (TSQ-WT) and the Quebec User Evaluation of Satisfaction with assistive Technology (QUEST)[17]. The USQ is rated on a 5-point Likert scale with 5 meaning to strongly agree and 1 to strongly disagree with a given statement.

Descriptor variables

Fall frequency was established retrospectively before the intervention through self-report. The Falls Efficacy Scale International (FES-I) was used to assess fear of falling[18]. Global cognitive function was measured using the MMSE and Montreal Cognitive Assessment (MoCA). Therapy compliance was indicated by the number of completed sessions (maximum 18) at the end of the intervention. Hoehn & Yahr stage and Unified Parkinson Disease Rating Scale (UPDRS) total score were determined for all PD-F. The Physical Activity Scale for the Elderly (PASE) was used to determine physical fitness. In addition, the Short-form health survey (SF-36) provided additional information on physical and mental health.

Statistical analyses

Statistical analyses were performed using SPSS (v.22.0, IBM). Significance levels were set at α=.05. Baseline group differences (participant demographics and background experience) were evaluated using Pearson Chi-squared statistics, Mann-Whitney U tests, and Independent t-tests. Intervention effects were analyzed using McNemar and Wilcoxon signed rank tests. A sub-analysis was performed including only participants without any fall prevention, treadmill training, or VR experience (n=125).

Spearman rank and point biserial correlation analyses examined the influence of experience on attitude formation. A Bonferroni correction was applied to correct for multiple testing (0.05/28). Baseline and post intervention attitudes were correlated with prior experiences (i.e. prior experience with fall prevention exercise, and prior experience with computer games), user satisfaction (i.e. USQ total score), and drop out. Some demographics were also included in the correlation analysis, namely age, MoCA, FES-I and fall frequency.

Results

In Figure 1, the study flow chart is presented. A total of 281 participants were enrolled in the study, of which 144 were randomized to TT+VR and 137 to TT. Nine participants dropped out post-intervention, as they did not complete the minimum required number of training sessions. In addition, four participants did not fill-out the post-intervention questionnaire. There were no significant differences between the intervention cohorts (TT *vs.* TT+VR) in terms of participant demographics (Table 1).

Attitudes questionnaire

Background experience

Background experiences are presented in Table 2. The majority of participants had never received falls prevention exercise (83.3%) and had no previous experience using a VR system, such as computer games (77.5%). Only 42.9% of the sample had prior experience with walking on a treadmill. Most of the participants who did have experience with treadmill walking or playing computer games enjoyed using these technologies (treadmill walking: 92.5%; computer games: 77%). These basic experiences and appreciation did not differ between exercise groups (TT+VR *vs.* TT) or faller cohorts (PD-F *vs.* MCI-F *vs.* HE-F) (Appendix 5).

Fall prevention exercise without virtual reality (n=281)

As shown in Table 3, most participants had a positive attitude towards fall prevention exercise at baseline (82.2%), and these remained positive following intervention (80.6%, p=.144). To reduce fall frequency, a combination of both motor and cognitive training was thought to be most effective, both at baseline (71.9%), and following intervention (75.6%). No attitude differences were found between the faller cohorts (PD-F *vs.* MCI-F *vs.* HE-F) (Appendix 6).

In a sub-analysis including only participants without any fall prevention, treadmill training, or VR experience (n=125), non-experienced participants showed similar outcomes, namely a positive attitude towards fall prevention exercise both pre (79%) and post intervention (82.8%; p=.531).

Fall prevention exercise with virtual reality (n=144)

At baseline, only 53.6% of participants had a positive attitude towards fall prevention exercise (Table 3). These attitudes positively changed following a TT+VR intervention (83.1%, p<.001). Whereas the majority of participants felt they would enjoy TT+VR at baseline (88.1%), an even larger proportion of participants agreed that TT+VR was in fact enjoyable post-intervention (99.2%, p<.001). Similar findings were obtained in a sub-analysis including non-experienced participants only (n=125), namely an improved attitude towards TT+VR from pre (53%) to post (85.2%; p=.004).

At baseline, the majority of the cohort envisaged that gait (92.8%), balance (90.2%), physical fitness (88.8%), obstacle negotiation (75.1%), and cognitive function (67.0%) would improve as a result of TT+VR. These expectations were generally met post-intervention: gait (91.5%), physical fitness (90.6%), obstacle crossing (85.3), and cognitive function (66.4%). However, fewer participants (77.3%) confirmed that TT+VR had improved balance.

At baseline, TT+VR was differently perceived between faller cohorts, with PD-F having more positive attitudes as opposed to HE-F (PD-F *vs.* HE-F: p=.017; PD-F *vs.* MCI-F: p=.796; HE-F *vs.* MCI-F: p=1.0). However, these differences were no longer present post-intervention (p=.435) (Appendix 6).

User Satisfaction Questionnaire

Table 4 provides the USQ responses in each of the intervention cohorts. The majority of the sample was satisfied (95.9%) and would recommend (89.8%) the intervention to other people in their situation, irrespective of treatment arm. Both interventions were considered to be safe (88.3%), engaging (74.1%), and an interesting challenge (88.3%) with beneficial effects for physical well-being (84.2%), walking (84.6%), obstacle crossing (72.6%) and concentration (60.2%). A large group of the sample (76.3%) felt more confident in their walking and thought the intervention had helped them to maintain their independence (78.6%).

Notably, a trend towards a higher USQ total score was found for those allocated to TT+VR as compared to TT (p=.052). TT+VR was found to be a significantly more engaging (p=.017) and an interesting challenge (p=.049), and it was thought to have larger positive effects on obstacle negotiation (p<.001) and concentration (p=.020) as compared to TT. Perhaps this explains why participants allocated to TT+VR were more prone to recommend the intervention to other people in their situation (p=.036).

HE-F were more convinced that TT+VR improved their ability to concentrate compared to PD-F (PD-F *vs.* HE-F: p=.005; PD-F *vs.* MCI-F: p=.598; HE-F *vs.* MCI-F: p=.846) (Appendix 7).

Correlation analyses

Attitudes towards fall prevention exercise with and without VR were not significantly correlated with age, global cognition (MoCA), fall frequency in the past 6 months, FES-I scores, prior experiences with fall prevention exercise, or prior experiences with computer games. However, the USQ total score significantly correlated with older people's post-intervention attitudes towards fall prevention exercise with and without VR. Importantly, no significant correlation was found between the baseline attitudes and drop-out. An overview is provided in Table 5.

Discussion

This study examined the attitudes of fall-prone older people with a range of cognitive and motor deficits towards fall prevention exercise with and without VR. The results show that most participants were positive about fall prevention exercise, yet, the idea of augmenting these interventions with VR was initially received with moderate enthusiasm. Following a six-week VR experience, older people's attitudes were favorably altered (from 61.5% to 83.7%) and this is in accordance with our a priori hypothesis. These findings are supported by correlation analyses which underline the importance of experience and user satisfaction in forming an attitude.

In contrast to our findings, earlier studies showed that the majority of older people are not receptive to fall prevention exercise and are not inclined to enroll in fall prevention interventions[19-21]. Low expectations of the anticipated benefits are considered to be an important predictor for participation and therapy adherence[22-24]. In the current study, however, baseline attitudes were more positive than could be expected based on previous research. This might be explained by the fact that participants had already agreed to partake in the fall prevention intervention (i.e. TT or TT+VR).

Importantly, those who were still skeptical about fall prevention exercise with or without VR at baseline, were not more prone to drop-out, as was shown in a correlation analysis. In addition, compliance was high regardless of intervention modality. Research has shown that people's acceptance of and participation in fall prevention interventions is influenced by previous experience[19]. This was not confirmed by our study, in which prior experience with fall prevention exercise and computer games showed no association with participants attitudes. However, it is of note that the majority of the sample had not previously participated in exercise for falls, and efforts should be made to improve service provision for falling populations internationally.

Early pilot work has indicated that once older people are introduced to VR, they describe it as fun, engaging and beneficial for treatment[25, 26]. Similarly, the present study showed that even though 46.4% of participants were skeptical about VR at baseline, the vast majority (83.1%) agreed that TT+VR was enjoyable and useful following intervention. Importantly, these findings did not differ between faller cohorts. Post intervention, fewer participants were convinced that TT+VR had improved their balance. Possibly, participants had unrealistically high expectation regarding their balance improvements, as they knew they would be enrolled in a fall prevention intervention.

To our knowledge, this is the first study to demonstrate that attitudes towards VR can positively change following exposure to it. Our findings are supported by the 'Behavioral Learning Theory' which suggests that an attitude change is facilitated by positively reinforcing a certain behavior[27]. By getting first-hand experience and actually undergoing the benefits of VR, older people became more enthusiastic about this new approach. In fact, participants allocated to TT+VR tended to have higher user satisfaction scores about the intervention provided. TT+VR was considered to be more engaging and challenging than TT, and was thought to have a higher impact on improving obstacle negotiation and concentration skills. The reasons for this success may be related to the quality of the VR, which was adapted to the specific needs of older fallers and fine-tuned according to cognitive and motor capacity[28, 29]. In addition, these results need to be viewed in the context of the fact that TT+VR was shown to be more effective than TT in reducing fall rates, and in improving gait variability and obstacle clearance, which may partly explain why participants allocated to TT+VR tended to be more satisfied.

A limitation of the study was the use of self-developed questionnaires, which was dictated by the study design. Extensive pilot testing was conducted to ensure that our instruments were valid and reliable. However, by using these instruments the comparison with other studies is limited and the generalizability of our findings compromised. In addition, forward translation of the questionnaires was done by researchers from the participating centers, but no backward translation was performed. The strength of the study lies in the large sample recruited across five countries encompassing a range of cognitive and motor abilities. Furthermore, the novel experimental manipulation of VR in comparison to an active control group allowed us to probe attitudes related to experience. This study only allowed comparison between TT+VR and TT. The latter can be considered a fairly regular training mode but comparison with a group receiving standard care would have enabled contrasting VR with ‘conventional approaches’, which constitutes a drawback of this study.

In conclusion, we have shown that participants were satisfied with both training interventions. While many older people initially held a reserved attitude towards VR technology, these attitudes were improved following intervention. Considering its effectiveness and the positive attitudes towards its use, the integration of VR into clinical practice needs further consideration. In fact, ensuring that exercise interventions both with and without VR are easily accessible for older populations, may generate a general positive attitude change and thus continue to improve overall health and physical functioning in older populations.

Declaration of Sources of Funding

This work was supported by the European Commission [7th Framework Programme project V-TIME-278169].

References

1. Tinetti ME, Speechley M, Ginter SF: **Risk factors for falls among elderly persons living in the community**. *N Engl J Med* 1988, **319**(26):1701-1707.
2. Allen NE, Schwarzel AK, Canning CG: **Recurrent falls in Parkinson's disease: a systematic review**. *Parkinsons Dis* 2013, **2013**:906274.
3. Liu-Ambrose TY, Ashe MC, Graf P, Beattie BL, Khan KM: **Increased risk of falling in older community-dwelling women with mild cognitive impairment**. *Phys Ther* 2008, **88**(12):1482-1491.
4. Gillespie LD, Robertson MC, Gillespie WJ, Sherrington C, Gates S, Clemson LM, Lamb SE: **Interventions for preventing falls in older people living in the community**. *The Cochrane database of systematic reviews* 2012, **9**:CD007146.
5. Keshner EA: **Virtual reality and physical rehabilitation: a new toy or a new research and rehabilitation tool?** *J Neuroeng Rehabil* 2004, **1**(1):8.
6. Goble DJ, Cone BL, Fling BW: **Using the Wii Fit as a tool for balance assessment and neurorehabilitation: the first half decade of "Wii-search"**. *J Neuroeng Rehabil* 2014, **11**:12.
7. Pietrzak E, Cotea C, Pullman S: **Using commercial video games for falls prevention in older adults: the way for the future?** *J Geriatr Phys Ther* 2014, **37**(4):166-177.
8. Toril P, Reales JM, Mayas J, Ballesteros S: **Video Game Training Enhances Visuospatial Working Memory and Episodic Memory in Older Adults**. *Front Hum Neurosci* 2016, **10**:206.
9. Dockx K, Van den Bergh V, Bekkers EMJ, Ginis P, Rochester L, Hausdorff JM, Mirelman A, Nieuwboer A: **Virtual reality for rehabilitation in Parkinson's disease**. *The Cochrane collaboration* 2016.
10. Mirelman A, Rochester L, Maidan I, Del Din S, Alcock L, Nieuwhof F, Rikkert MO, Bloem BR, Pelosin E, Avanzino L *et al*: **Addition of a non-immersive virtual reality component to treadmill training to reduce fall risk in older adults (V-TIME): a randomised controlled trial**. *Lancet* 2016, **388**(10050):1170-1182.
11. Mirelman A, Rochester L, Reelick M, Nieuwhof F, Pelosin E, Abbruzzese G, Dockx K, Nieuwboer A, Hausdorff JM: **V-TIME: a treadmill training program augmented by virtual reality to decrease fall risk in older adults: study design of a randomized controlled trial**. *BMC Neurol* 2013, **13**:15.
12. Folstein MF, Folstein SE, McHugh PR: **"Mini-mental state". A practical method for grading the cognitive state of patients for the clinician**. *J Psychiatr Res* 1975, **12**(3):189-198.
13. Morris JC: **Clinical dementia rating: a reliable and valid diagnostic and staging measure for dementia of the Alzheimer type**. *Int Psychogeriatr* 1997, **9 Suppl 1**:173-176; discussion 177-178.
14. Hughes AJ, Daniel SE, Kilford L, Lees AJ: **Accuracy of clinical diagnosis of idiopathic Parkinson's disease: a clinico-pathological study of 100 cases**. *J Neurol Neurosurg Psychiatry* 1992, **55**(3):181-184.
15. Hoehn MM, Yahr MD: **Parkinsonism: onset, progression and mortality**. *Neurology* 1967, **17**(5):427-442.
16. **World Medical Association Declaration of Helsinki. Ethical principles for medical research involving human subjects**. *Bull World Health Organ* 2001, **79**(4):373-374.
17. Demers L, Weiss-Lambrou R, Ska B: **Development of the Quebec User Evaluation of Satisfaction with assistive Technology (QUEST)**. *Assistive technology : the official journal of RESNA* 1996, **8**(1):3-13.
18. Yardley L, Beyer N, Hauer K, Kempen G, Piot-Ziegler C, Todd C: **Development and initial validation of the Falls Efficacy Scale-International (FES-I)**. *Age Ageing* 2005, **34**(6):614-619.
19. Bunn F, Dickinson A, Barnett-Page E, Mcinnes E, Horton K: **A systematic review of older people's perceptions of facilitators and barriers to participation in falls-prevention interventions**. *Ageing Soc* 2008, **28**:449-472.

20. Hughes K, van Beurden E, Eakin EG, Barnett LM, Patterson E, Backhouse J, Jones S, Hauser D, Beard JR, Newman B: **Older persons' perception of risk of falling: implications for fall-prevention campaigns**. *Am J Public Health* 2008, **98**(2):351-357.
21. Faes MC, Reelick MF, Joosten-Weyn Banningh LW, Gier M, Esselink RA, Olde Rikkert MG: **Qualitative study on the impact of falling in frail older persons and family caregivers: foundations for an intervention to prevent falls**. *Aging Ment Health* 2010, **14**(7):834-842.
22. Ellis T, Boudreau JK, DeAngelis TR, Brown LE, Cavanaugh JT, Earhart GM, Ford MP, Foreman KB, Dibble LE: **Barriers to exercise in people with Parkinson disease**. *Phys Ther* 2013, **93**(5):628-636.
23. Forkan R, Pumper B, Smyth N, Wirkkala H, Ciol MA, Shumway-Cook A: **Exercise adherence following physical therapy intervention in older adults with impaired balance**. *Phys Ther* 2006, **86**(3):401-410.
24. Resnick B, Spellbring AM: **Understanding what motivates older adults to exercise**. *J Gerontol Nurs* 2000, **26**(3):34-42.
25. Lange BS, Requejo P, Flynn SM, Rizzo AA, Valero-Cuevas FJ, Baker L, Winstein C: **The potential of virtual reality and gaming to assist successful aging with disability**. *Phys Med Rehabil Clin N Am* 2010, **21**(2):339-356.
26. Marivan K, Boully C, Benveniste S, Reingewirtz S, Rigaud AS, Kemoun G, Bloch F: **Rehabilitation of the psychomotor consequences of falling in an elderly population: A pilot study to evaluate feasibility and tolerability of virtual reality training**. *Technol Health Care* 2016, **24**(2):169-175.
27. Smith PL, Ragan TJ: **Instructional design**. *New York: John Wiley & Sons* 1999.
28. Lewis GN, Rosie JA: **Virtual reality games for movement rehabilitation in neurological conditions: how do we meet the needs and expectations of the users?** *Disabil Rehabil* 2012, **34**(22):1880-1886.
29. Lyons EJ: **Cultivating Engagement and Enjoyment in Exergames Using Feedback, Challenge, and Rewards**. *Games for health journal* 2015, **4**(1):12-18.

Figure 1. Study design

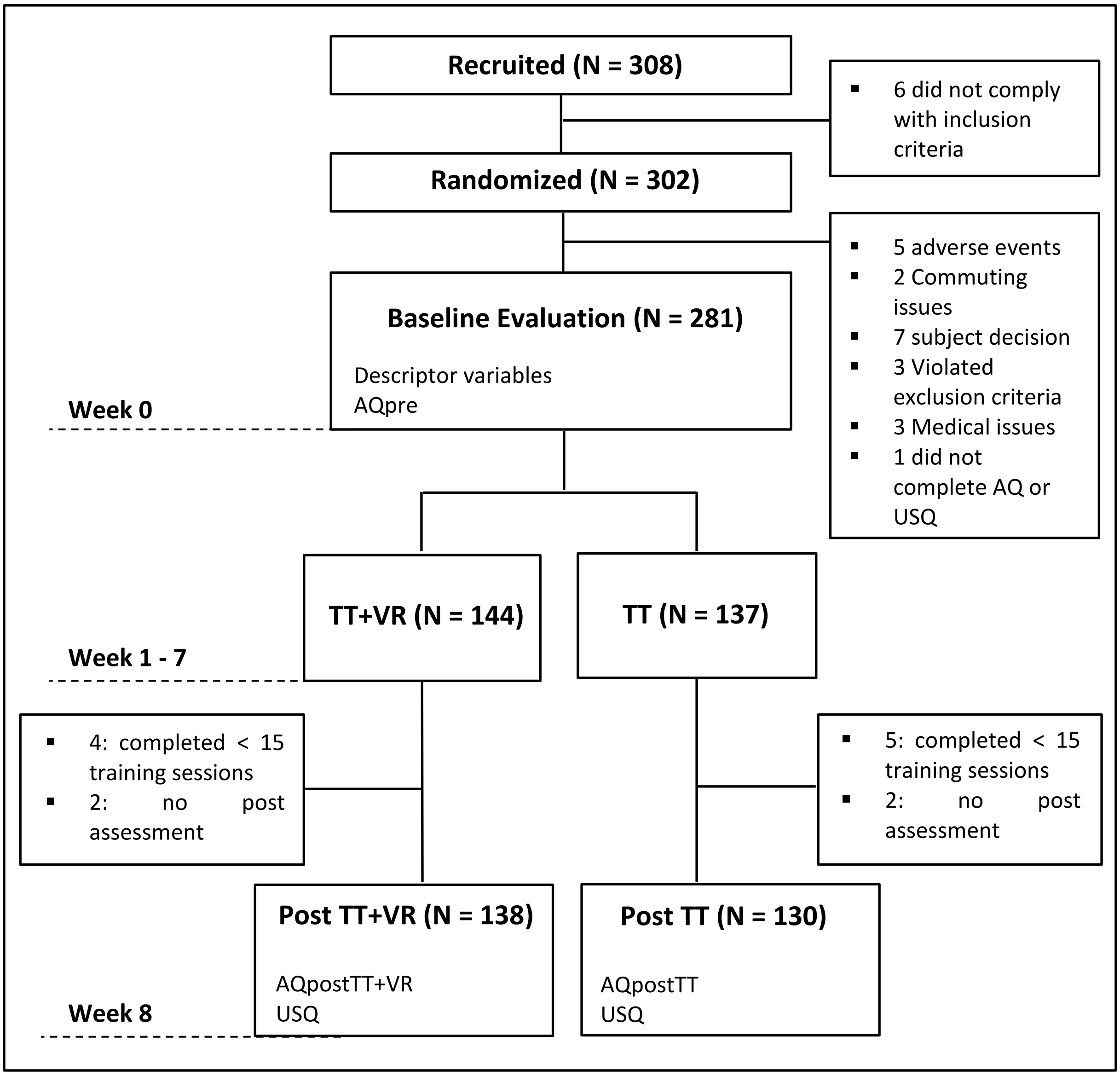


Figure 2. Setting of a treadmill augmented by a virtual reality system

Table 1. Participant demographics

	TT+VR (n = 144)	TT (n = 137)	p-value
Age [yrs] [a]	74.2 (±7.0)	73.3 (±6.3)	.226
Gender [male/female]	57/87	57/80	.808
Cohort [HE-F/MCI-F/PD-F]	56/23/65	52/21/64	.964
Education [yrs]	13.1 (±4.0)	12.8 (±4.1)	.798
PASE	99.8 (±57.0)	98.2 (±64.4)	.453
SF-36 Physical health	54.6 (±18.8)	53.8 (±20.7)	.183
SF-36 Mental health	61.0 (±18.8)	59.5 (±21.1)	.059
Fall frequency 6 months [#] [b]	3 (2-4)	2 (2-4)	.919
FES-I [16-64] [b]	28 (22.8-37)	30 (23-38)	.199
MMSE [24-30] [b]	28 (27-29)	29 (27-30)	.096
MoCA [0-30] [b]	24 (21-27)	25 (22-27)	.431
Therapy compliance [0-18] [b]	17 (16-18)	17 (16-18)	.292
Hoehn & Yahr stage [2/2.5/3] [bc]	33/8/24	28/6/30	.313
UPDRS total score [0-260] [bc]	58 (46-73)	63.5 (48.3-79.5)	.311

Yrs: years; HE-F: Healthy elderly faller; MCI-F: Faller with Mild Cognitive Impairment; PD-F: Faller with Parkinson's disease; FES-I: Falls Efficacy Scale-International; MMSE: Mini Mental State Examination; MoCA: Montreal Cognitive Assessment; TT+VR: Treadmill training + Virtual reality; TT: Treadmill training.

[a] Values are presented as mean (± standard deviation)

[b] Values are presented as median (Inter Quartile Range)

[c] Analysis performed on PD patients only (n = 129)

[*] $p \leq .05$

Table 2. Attitudes questionnaire part i) Background experience

	TT+VR (n = 144)	TT (n = 137)	p-value
Experience with fall prevention [Y/N]	25/116 (17.7%)	21/113 (15.7%)	.747
Experience with TT [Y/N]	62/79 (44.0.%)	56/78 (41.8%)	.807
Experience with computer games [Y/N]	27/114 (19.1%)	35/99 (41.0%)	.194
Enjoy TT [Y/N]	58/5 (92.1%)	53/4 (93.0%)	1.0
Enjoy playing computer games [Y/N]	21/6 (77.8%)	26/8 (76.5%)	1.0

Y: Yes; N: No; TT+VR: Treadmill training + Virtual reality; TT: Treadmill training

Table 3. Attitudes questionnaire with a) Attitudes towards fall prevention exercise without VR; b) Attitudes towards fall prevention exercise with VR

	Pre (n = 275) [a]	**Post (n = 129)** [c]	**p-value**
a. Attitudes towards fall prevention exercise without VR			
It is possible to lower the amount of falls or prevent them by training?			.144
Strongly agree	77 (28.0%)	43 (33.3%)	
Agree	149 (54.2%)	61 (47.3%)	
Neither agree nor disagree	42 (15.3%)	21 (16.3%)	
Disagree	3 (1.1%)	4 (3.1%)	
Strongly disagree	4 (1.4%)	0 (0.0%)	
	Pre (n = 269) [b]	**Post (n = 130)** [d]	**p-value**
b. Attitudes towards fall prevention exercise with VR [b]			
Virtual reality exercise can reduce the number of falls?			<.001*
Strongly agree	29 (10.8%)	35 (26.9%)	
Agree	115 (42.8%)	73 (56.2%)	
Neither agree nor disagree	113 (42.0%)	20 (15.4%)	
Disagree	8 (3.0%)	2 (1.5%)	
Strongly disagree	4 (1.4%)	0 (0.0%)	
Will / Did you enjoy a TT+VR? (Y/N)	237/32 (88.1%)	130/1 (99.2%)	<.001*
Will / Did you improve …. following TT+VR? (Y/N)			
Gait	246/19 (92.8%)	119/11 (91.5%)	.424
Balance	240/26 (90.2%)	99/29 (77.3%)	<.001*
Physical fitness	237/30 (88.8%)	116/12 (90.6%)	.824
Obstacle negotiation	199/66 (75.1%)	110/19 (85.3%)	.626
Cognitive function	177/87 (67.0%)	85/43 (66.4%)	.440

VR: Virtual reality; TT+VR: Treadmill training + Virtual reality; Y: Yes; N: No.

[a] Analyses performed on the entire cohort (N = 281), with missing data from n = 6

[b] Analyses performed on the entire cohort (N = 281), with missing data from n = 12

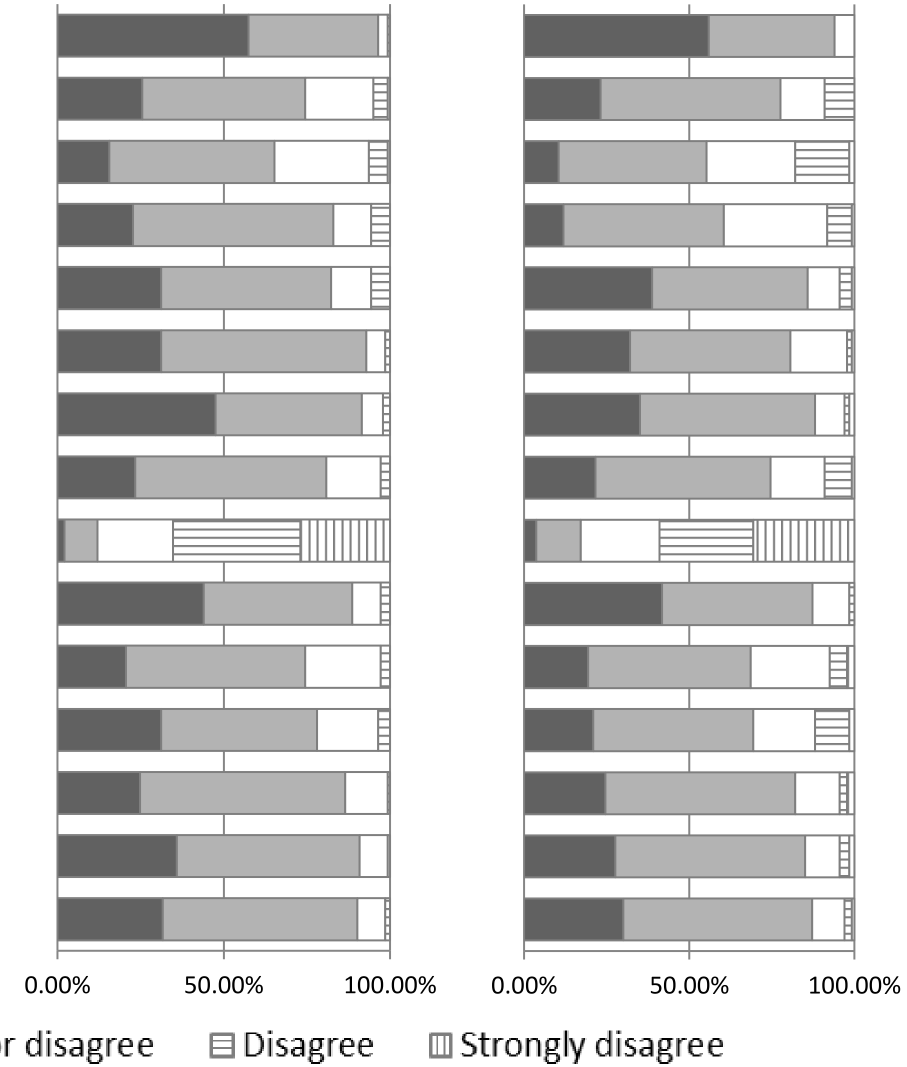
[c] Analyses performed on TT cohort (N = 130), with missing data from n = 1

[d] Analyses performed on TT+VR cohort (N = 138), with missing data from n = 8

[*] $p \leq .05$

Table 4. Group differences on the user satisfaction questionnaire

User Satisfaction Questionnaire	TT+VR (n = 138)	TT (n = 130)	P-value
User satisfaction Total Score (15-75)	**31.91 (±7.74)**	**30.00 (±6.94)**	0.052
Q15:I feel satisfied by the training provided			0.693
Q14: I feel more confident in walking			0.931
Q13: I feel my ability to concentrate / focus has improved			0.020*
Q12: I feel my ability to negotiate obstacles had improved			<0.001*
Q11: I feel my walking has improved			0.175
Q10: This technology has a positive effect on me			0.226
Q9: I would recommend this technology to other people in my situation			0.036*
Q8: This technology helps me to maintain or increase my independence			0.253
Q7: Use of this technology can have negative consequences I can't predict			0.621
Q6: I feel safe when using this technology			0.695
Q5: This technology is helping me to achieve my goals			0.305
Q4: This technology is engaging			0.017*
Q3: Using this technology improves my physical well-being			0.514
Q2: The use of this technology is an interesting challenge for me			0.049*
Q1: I can benefit from this technology			0.486



TT+VR: Treadmill training + Virtual reality; TT: Treadmill training.
* p ≤ .05

Table 5. Correlation matrix with a) Attitudes towards fall prevention exercise without VR; b) Attitudes towards fall prevention exercise with VR

	Pre (n = 275) [a]		Post (n = 129) [c]	
	r	p-value	r	p-value
a. Attitudes towards fall prevention exercise without VR [a]				
Age	.016	.795	.091	.304
MoCA	.056	.387	-.048	.589
Fall frequency 6 months	.082	.174	.038	.673
FES-I	.008	.896	.037	.685
Experience with fall prevention	.167	.005	.038	.669
Experience with computer games	-.079	.193	-.138	.122
USQ total score	-	-	.405	<.001*
Drop-out	-.038	.525	-	-

	Pre (n = 269) [b]		Post (n = 130) [d]	
	r	p-value	R	p-value
b. Attitudes towards fall prevention exercise with VR [b]				
Age	.006	.918	-.033	.713
MoCA	.084	.171	.123	.163
Fall frequency 6 months	-.070	.250	-.169	.056
FES-I	-.108	.078	.022	.806
Experience with fall prevention	.087	.155	-.113	.206
Experience with computer games	.071	.246	.003	.973
USQ total score	-	-	.503	<.001*
Drop-out	.073	.233	-	-

VR: Virtual reality; MoCA: Montreal Cognitive Assessment; FES-I: Falls Efficacy Scale; USQ: user satisfaction questionnaire.

[a] Analyses performed on the entire cohort (N = 281), with missing data from n = 6

[b] Analyses performed on the entire cohort (N = 281), with missing data from n = 12

[c] Analyses performed on TT cohort (N = 130), with missing data from n = 1

[d] Analyses performed on TT+VR cohort (N = 138), with missing data from n = 8

[*] p ≤ .0018 (=.05/28)

Appendices

Appendix 1: Attitudes Questionnaire Pre (AQpre)

Part i) Background experience

1. Have you ever received a rehabilitation or training program, in order to lower the amount of falls? Yes – No
2. Do you have any previous experience with walking on a treadmill? Yes – No
3. If yes, do you enjoy walking on a treadmill? Yes - No
4. Do you have any previous experience with a virtual reality system (e.g. computergames, Playstation, Nintendo Wii, …)? Yes - No
5. If yes, do you enjoy playing computer games? Yes - No

Part ii) Attitudes towards fall prevention exercise without VR

1. To what extent do you agree with the following statement: It is possible to lower the amount of falls or prevent them by training? Strongly agree – Agree – Neither agree nor disagree – Disagree – Strongly disagree
2. Which type of training can, according to you, lower the amount of falls or prevent them? Motor training – Cognitive training – Combination of both motor and cognitive components

Part iii) Attitudes towards fall prevention exercise with VR

3. To what extent do you agree with the following statement: Virtual-reality treadmill training can reduce the number of falls? Strongly agree – Agree – Neither agree nor disagree – Disagree – Strongly disagree
4. Will, according to you, the following items improve after a virtual reality-treadmill training program?
    a. Physical fitness Yes – No
    b. Cognitive function Yes – No
    c. Walking Yes – No
    d. Balance Yes – No
    e. Avoiding obstacles Yes – No
5. Do you think you would enjoy a virtual reality-treadmill training intervention (three, one hour sessions, per week for six weeks)? Yes - No

Appendix 2: Attitudes Questionnaire Post TT+VR (AQpostTT+VR)

Part iii) Attitudes towards fall prevention exercise with VR

1. To what extent do you agree with the following statement: Virtual-reality treadmill training can reduce the number of falls? Strongly agree – Agree – Neither agree nor disagree – Disagree – Strongly disagree
2. Did, according to you, the following items improve after a virtual reality-treadmill training program?
    a. Physical fitness Yes – No
    b. Cognitive function Yes – No
    c. Walking Yes – No
    d. Balance Yes – No
    e. Avoiding obstacles Yes – No
3. Did you enjoy a virtual reality-treadmill training intervention (three, one hour sessions, per week for six weeks)? Yes – No

Appendix 3: Attitudes Questionnaire Post TT (AQpostTT)

Part ii) Attitudes towards fall prevention exercise without VR

1. To what extent do you agree with the following statement: It is possible to lower the amount of falls or prevent them by training? Strongly agree – Agree – Neither agree nor disagree – Disagree – Strongly disagree
2. Which type of training can, according to you, lower the amount of falls or prevent them? Motor training – Cognitive training – Combination of both motor and cognitive components

Appendix 4: User Satisfaction Survey

	To what extent do you agree with the following statements:	1 Strongly disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly agree
	Part i) Benefits and pitfalls of the intervention					
1	I can benefit from this technology					
2	The use of this technology is an interesting challenge for me					
3	I feel satisfied by the training provided					
4	This technology is engaging					
5	This technology is helping me to achieve my goals					
6	I feel safe when using this technology					
7	The use of this technology can have negative consequences I can't predict					
8	This technology helps me to maintain or increase my independence					
9	I would recommend this technology to other people in my situation					
10	This technology has a positive effect on me					
Part ii) Self-perceived improvements on physical and cognitive outcome measures						
13	I feel my walking has improved					
14	I feel my ability to negotiate obstacles had improved					
15	I feel my ability to concentrate / focus has improved					
16	I feel more confident in walking					
17	Using this technology improves my physical well-being					

Appendix 5. Differences between PD-F, MCI-F and HE-F on the attitudes questionnaire part i) Background experience

	PD-F (n=125)	MCI-F (n=43)	HE-F (n=107)	p-value
Experience with fall prevention [Y/N]	22/103 (17.6%)	7/36 (16.3%)	17/90 (15.9%)	.938
Experience with TT [Y/N]	57/68 (45.6%)	13/30 (30.2%)	48/59 (44.9%)	.187
Experience with computer games [Y/N]	31/94 (24.8%)	11/32 (25.6%)	20/87 (18.7%)	.472
Enjoy TT [Y/N]	54/3 (94.7%)	12/2 (85.7%)	45/4 (91.8%)	.504
Enjoy playing computer games [Y/N]	27/4 (87.1%)	7/3 (70.0%)	13/7 (65.0%)	.158

Y: Yes; N: No; TT+VR: Treadmill training + Virtual reality; TT: Treadmill training

Appendix 6. Differences between PD-F, MCI-F and HE-F on the attitudes questionnaire

	Pre				Post			
	PD-F (n=125)	MCI-F (n=43)	HE-F (n=107)	p-value	PD-F (n=61)	MCI-F (n=20)	HE-F (n=48)	p-value
c. Attitudes towards fall prevention exercise without VR [a]								
It is possible to lower the amount of falls or prevent them by training?				.656				.625
Strongly agree	33 (26.4%)	11 (25.6%)	33 (30.8%)		22 (36.1%)	5 (25.0%)	16 (33.3%)	
Agree	68 (54.4%)	24 (55.8%)	57 (53.3%)		27 (44.2%)	10 (50.0%)	24 (50.0%)	
Neither agree nor disagree	20 (16%)	8 (18.6%)	14 (13.1%)		10 (16.4%)	4 (20.0%)	7 (14.6%)	
Disagree	2 (1.6%)	0 (0.0%)	1 (0.9%)		2 (3.3%)	1 (5.0%)	1 (2.1%)	
Strongly disagree	2 (1.6%)	0 (0.0%)	2 (1.9%)		0 (0.0%)	0 (0.0%)	0 (0.0%)	
	PD-F (n=123)	**MCI-F (n=43)**	**HE-F (n=104)**	**p-value**	**PD-F (n=59)**	**MCI-F (n=21)**	**HE-F (n=50)**	**p-value**
d. Attitudes towards fall prevention exercise with VR [b]								
Virtual reality exercise can reduce the number of falls?				.029				.435
Strongly agree	17 (13.8%)	4 (9.3%)	8 (7.8%)		17 (28.8%)	9 (42.9%)	9 (18.0%)	
Agree	58 (47.2%)	18 (41.9%)	39 (37.8%)		31 (52.5%)	8 (38.1%)	34 (68.0%)	
Neither agree nor disagree	45 (36.6%)	20 (46.5%)	48 (46.6%)		10 (17.0%)	4 (19.0%)	6 (12.0%)	
Disagree	3 (2.4%)	1 (2.3%)	4 (3.9%)		1 (1.7%)	0 (0.0%)	1 (2.0%)	
Strongly disagree	0 (0.0%)	0 (0.0%)	4 (3.9%)		0 (0.0%)	0 (0.0%)	0 (0.0%)	
Will / Did you enjoy a TT+VR? (Y/N)	109/13 (89.3%)	38/5 (88.4%)	90/14 (86.5%)	.808	58/1 (98.3%)	21/0 (100%)	50/0 (100%)	.545
Will / Did you improve …. following TT+VR? (Y/N)								
Gait	114/6 (95.0%)	39/3 (92.9%)	93/10 (90.3%)	.397	51/8 (86.4%)	21/0 (100%)	47/3 (94.0%)	.116
Balance	107/14 (88.4%)	38/4 (90.5%)	95/8 (92.2%)	.633	42/17 (71.2%)	16/4 (80.0%)	41/8 (83.7%)	.290
Physical fitness	109/13 (89.3%)	39/3 (92.9%)	89/14 (86.4%)	.517	51/7 (87.9%)	21/0 (100%)	44/5 (89.8%)	.258
Obstacle negotiation	90/30 (75.0%)	28/14 (66.7%)	81/22 (78.6%)	.319	48/11 (81.4%)	18/3 (85.7%)	44/5 (89.8%)	.467
Cognitive function	76/43 (63.9%)	28/14 (66.7%)	73/30 (70.9%)	.540	34/24 (58.6%)	16/5 (76.2%)	35/14 (71.4%)	.220

VR: Virtual reality; TT+VR: Treadmill training + Virtual reality; Y: Yes; N: No.

[a] Analyses performed on the entire cohort (pre: N = 281; post: N = 268)

[b] Analyses performed on the TT+VR cohort only (pre: N = 144; post: N = 138)

[*] $p \leq .05$

Appendix 7. Group differences on the user satisfaction questionnaire